DESIGN OF A 2.4 GHZ SPREAD SPECTRUM TRANSCEIVER

CONWAY AK. BEDDIE

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CONWAY AK. BEDDIE

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ABSTRACT

This paper presents the design of a 2.4 GHz spread spectrum transceiver. Modern communication system is moving towards digital communication. Spread spectrum technique is one the method that can be used in digital communication. One important component in a communication system is a transceiver. A transceiver is a combination of a transmitter and a receiver. It is used to receive and transmit signal or data in a single medium. The transceiver that will be described in this report is the 2.4GHz spread spectrum transceiver. The chosen frequency of 2.4 GHz is an unlicensed frequency. This frequency is within the Industrial, Scientific and Medical (ISM) band as stated by the Federal Communication Commission (FCC).

ABSTRAK

Laporan ini menerangkan mengenai rekabentuk sebeuah transiver 2.4GHz. Sistem komunikasi moden telah menuju ke arah komunikasi secara digital. Salah satu kaedah yang dapat digunakan adalah kaedah penyebaran spectrum. Salah satu bahagian yang amat penting di dalam sesebuah system komunikas adalah transiver. Transiver adalah gabungan di antara sebuah pemancar dan penerima isyarat. Ianya berfungsi untuk memancar atau menerima isyarat dengan hanya menggunakan sebuah medium. Frekuensi yang dipilih iaitu 2.4GHz merupakan frekuensi tidak berlesen seperti yang dibenarkan oleh Federal Communication Commision (FCC). Di dalam laporan ini disertakan juga beberapa buah keputusan simulasi yang telah dijalankan.

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CHAPTER 1

1.0 INTRODUCTION

In a general term, communication can be referred to the act of sending, receiving and processing of information. Communication had always been an important aspect in human life. People had been trying to communicate with each other in various ways. In the early stage, primitive method such as smoke, papers and messenger is used. These methods however are not very efficient and time consuming especially for a long distance communication.

A new era for communication started in the year 1837 with the invention of telegraph by Samuel Morse. This success was followed by the development of telephone in 1876, thanks to the great mind of Alexander Graham Bell. In 1894, Guglielmo Marconi provides the first complete system of wireless communication. However, it is Lee DeForest that really opened the door for wireless communication with his invention of triode vacuum tube in 1908. Wireless communication using radio frequencies was greatly improved especially for military purpose during the World War II. Radio communication become even more widely used and refined through the invention and use of the transistor, integrated circuits and other semiconductor devices.

Most communication systems today are moving towards wireless technology. It can be use reduce problems like geographical barriers, to lower the maintenance cost and increasing the efficiency of the system in terms of speed and capacity. Wireless technologies are widely used in mobile communication. In the first generation system, analog system is used. Examples of analog system are AMPS, N-AMPS, NTT and TACS.

Advanced Mobile Phone System or AMPS was developed by Bell Labs in the 1970s and first used commercially in the United States in 1983. It operates in the 800 and 1900MHz in the United States and is the most widely distributed analog cellular standard. Then came other systems like the Narrowband Advanced Mobile Phone System, also known as N-AMPS, that is an interim technology between analog and digital. It has a greater capacity than the AMPS. Another system is the Total Access communication System or TACS, developed by Motorola. It is similar to AMPS but it operates in the 900MHz frequency range. It was first used in UK in 1985. It is called JTAC in Japan.

The emergence of the second-generation system has paved the way for digital communication. Some examples of this system are CDMA, GSM, DECT and PCS. The move from analog to digital communication has greatly improved the efficiency of modern communication system. More data could be send in a faster rate. Global System for Mobile Communications or GSM was the first European digital standard, developed to establish cellular compatibility throughout Europe. Its success has spread to all parts of the world. It operates at 900MHz and 1800MHz in many parts of Europe while in some part of the United States the 1900MHz is used. The CDMA (Code Division Multiple Access) enable multiple users to use the same frequency simultaneously. It employs the spread spectrum technique and some coding scheme.

The third generation system is still a new technology and is not widely used compared to the previous systems. This new generation includes the Bluetooth technology and the UMTS (Universal Mobile Telephone Standard). Meanwhile, the fourth generation system is still under research and would provide a variety of applications to the users.

From all the systems above, the second generation seems to be the most practically used nowadays. The spread spectrum technique used in CDMA is not a new technique after all. It was developed during the World War II meant for secret military communication and for radar countermeasures. It has been developed further that enable it to be used for other commercial applications.

In spread spectrum communication systems, one of the most important part is the transceiver. Transceiver is the combination of a transmitter and receiver. Without a transceiver, the system is useless because the data could not be transmitted or received. The frequency range of the transceiver determines the speed and capacity of the data. Thus, this report would tell the design of a 2.4GHz spread spectrum transceiver.

CHAPTER 2

2.0 SPREAD SPECTRUM TECHNOLOGY

The spread spectrum method is not a new technology in the history of communication systems. It has been used during the World War II by the US military for secret communication. Knowing the potential of the spread spectrum method, scientists have been doing a lot of research to develop this technique. As a result, the usage of spread spectrum technology has been widened to not only for military purpose but also for commercial applications.

2.1 Definition of spread spectrum

Spread spectrum may be defined as "...a technique in which an auxiliary modulation waveform, independent of the information data, is employed to spread the signal energy over a bandwidth much greater than the signal information bandwidth."

There are two main criteria of a spread spectrum signal. First, the bandwidth of the transmitted signal must be greater than the bandwidth of the information signal. This condition is needed to enable the spreading of the information signal within the transmitted bandwidth. The second criteria is that other than the data to be transmitted, some function such as code or pattern is employed to determine the transmitted bandwidth. The commonly used code is the pseudorandom noise code (PN code).

2.2 The advantages of spread spectrum

The main advantages of spread spectrum signaling are its ability to resist jamming and low probability of intercept. In spread spectrum technique, the data signals to be transmitted are coded using the PN codes and it is distributed over a range of frequencies. At the receiving end, the signals are collected and decoded back into their original frequency using some codes common to both the transmitter and receiver. The received noise usually has a very narrow bandwidth compared to the transmitted signal and thus it would likely interfere a very small portion of the signal. This makes the desired signal becoming transparent and unlikely to interfere or to be intercepted by other signal, even by signal transmitted on the same frequency. In other words, it is useful for signal hiding and noninterference with conventional system.

Since it could reject interference, this shows that the system has security and privacy features. Besides that, spread spectrum can also be used for accurate ranging and this feature makes it useful in radar system. Other advantages of spread spectrum are its capability to handle multiple access and multiple mitigation. These capabilities are the contributing factors to the growing interest on spread spectrum system development. It helps to reduce congestions and delay, hence it helps to improve the system performance.

2.3 Spread Spectrum and Multiple Access Techniques

One of the important aspects in wireless communication system is multiple random access. It is a great advantage to have communication links that can be activated at any time even if there are other links being used simultaneously. There are three main concepts that can be used to implement multiple access system. These three concepts are Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). Sometimes the combination of two techniques is also used such as the combination of TDMA and FDMA.

Frequency Division Multiple Access (FDMA) is commonly used in the conventional telephone system. A certain frequency band is assigned to every user to enable them to perform their communication. Assignment of the channels to every user can be done centrally or by carrier sensing in a mobile. Carrier sensing would enables random access. In FDMA, the frequency spectrum will not be fully utilized if only a few users are active.

The next concept, the Time Division Multiple Access (TDMA), assign every user a set of time slots. Data can only be transmitted during the time slot. After that, the transmitter needs to wait for another time slot before the next data can be transmitted. A central unit is needed to control the synchronization of all users and the assignment of time slots. This technique is difficult to apply in random access systems.

Meanwhile, in Code Division Multiple Access (CDMA) technique, a unique code is assigned to every user. The data message is coded and the codes are selected for low cross-correlation properties. All users can transmit simultaneously using the same frequency band while the receivers can still recover the desired signal. Since synchronization is not required, it will be possible to have random access system using the CDMA technique.

From the three techniques above, both the FDMA and CDMA would enable random access. However, CDMA is the most preferred technique. This is because it provides interference-limited operation. Since the whole frequency spectrum is used, more users are active and the interference level will increase higher. The next reason is because it provides privacy due to the unknown codes. CDMA also reduced the influence of narrow-band fades by using a wide frequency band. Besides that, this technique enables random access and it has a good anti-jamming performance. Due to the reasons above, the CDMA has become a very suitable choice to enable multiple access in a spread spectrum system.

2.4 Spread spectrum modulation techniques

Modulation is a process in which the transceiver prepared the digital signal for transmission. In spread spectrum modulation, the signal's power is spread over a wider band of frequencies that makes it less susceptible to electrical noise compared to the other conventional radio modulation techniques. This is because noise typically has a narrower bandwidth and would only interfere with a small portion of the spread spectrum signal.

The Federal Communications Commission (FCC) allowed the wireless network products to operate in the Industrial, Scientific and Medical (ISM) band using spread spectrum modulation. The ISM frequencies are 902-928 MHz, 2.4-2.4835 GHz and 5.725-5.850 GHz.

Band	Bandwidth
902-928 MHz	26.0 MHz
2.4-2.4835 GHz	83.5 MHz
5.725-5.850 GHz	125.0 MHz

Table 1 : ISM frequency band

Spread spectrum technology uses wide band and noise-like signals. Since the signal is noise-like, it is hard to detect or intercept the signal. Spread spectrum signals use fast codes called the Pseudo Random or Pseudo Noise codes.

There are several spread spectrum techniques. Two of the most commonly used techniques are the frequency hoping (FH) and the direct sequence (DS) technique. Other techniques available are hybrid DS/FH, chirp and time hoping.

2.4.1 Frequency Hoping (FH)

In frequency hoping spread spectrum technique, the bandwidth is divided into N channels. The information signal is modulated with the carrier signal that hops between these channels as a function of time. Using this technique, the carrier frequency will change periodically. Thus, interference can be reduced because the narrowband noise will only interfere the spread spectrum signal if both of them are transmitting at the same frequency at the same time. The aggregate interference will be very minimum, and resulting in little or no bit errors.

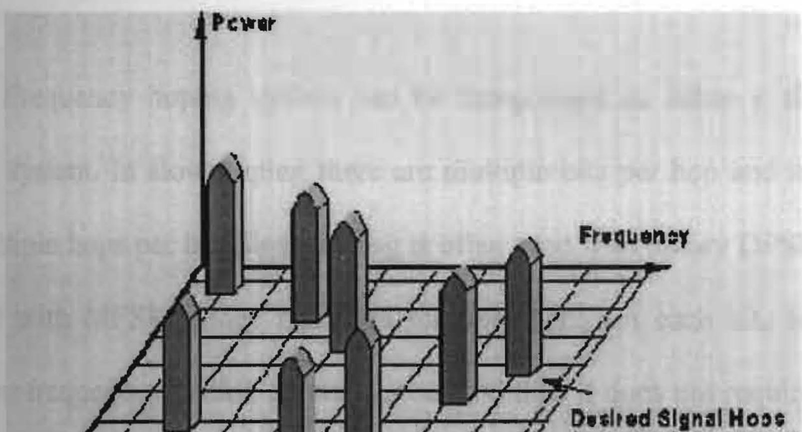

Figure 1 : Frequency Hoping

A hopping code is used to determine the frequencies and the order of the signal to be transmitted. Therefore, the receiver needs to be set to the same hoping codes and listen to the incoming signal at the right time and correct frequencies. The FCC regulation require the usage of 75 or more frequencies per transmission channel with a maximum time of 400ms spent at a particular frequency during any single hop. If one frequency encountered interference, the signal will be retransmitted at the subsequent hop on a different frequency.

The hops can cause phase discontinuity. Thus, a noncoherent modulation format such as the M-ary frequency-shift keying (MFSK) or differentially coherent phase-shift keying (PSK) modulation is often used. Higher order MFSK such as M equal to 8 or 16 may increase energy efficiency without increasing the spread bandwidth. Forward error correction (FEC) coding is often employed to provide protection for those data bits transmitted at a hop frequency with interference or with a fade.

Frequency hoping system can be categorized as either a slow-hoping or fast-hoping system. In slow-hoping there are multiple bits per hop and in fast- hoping there are multiple hops per bit. Slow-hoping is often used with binary DPSK while fast-hoping is used with MFSK. Since there are multiple hops for each bit, fast-hoping provides different frequencies within a data symbol and thus it does not require coding. However, one may encounter loss associated with post-detection integration because the MFSK detection on a per-hop basis. This loss can be compensated using the forward error coding (FEC). For the slow-hoping, the coding system needs to provide frequency diversity through interleaving in order to deal with the error bursts.

2.4.2 Direct Sequence (DS)

In direct sequence method, a sequence of zeros and ones called the pseudo-noise (PN) is used to phase modulate the data signal. The PN code has a higher frequency and bandwidth than the data, thus it spreads the data signal in the frequency plain. Direct sequence system usually use binary phase-shift keying (BPSK) modulation that is simpler than the higher order phase-shift keying (PSK) format such as the quaternary phase-shift keying (QPSK).

BPSK can be achieved by mod-2 adding the PN chip sequence with the data. The processing gain can be measured from the number of PN chips per bit. The FCC allows a minimum processing gain of 10. Thus, as an example, if a data bit equal to 1 is transmitted, a sequence of 00010011100 is being sent. Meanwhile, the QPSK is more complex. It is sometimes used to prevent signal capture when a strong interferer drives the receiver into saturation. The usage of a higher order PSK does not increase the processing gain. Due to this reason, the BPSK format is mostly preferred.

Direct sequence system can be categorized as either long-code or short-code systems. For long-code system, the code length is much longer than a data symbol so that each symbol has a different chip pattern. The chip sequence is random for a sufficiently long code. In short-code system, the same sequence is used repetitively for each data symbol.

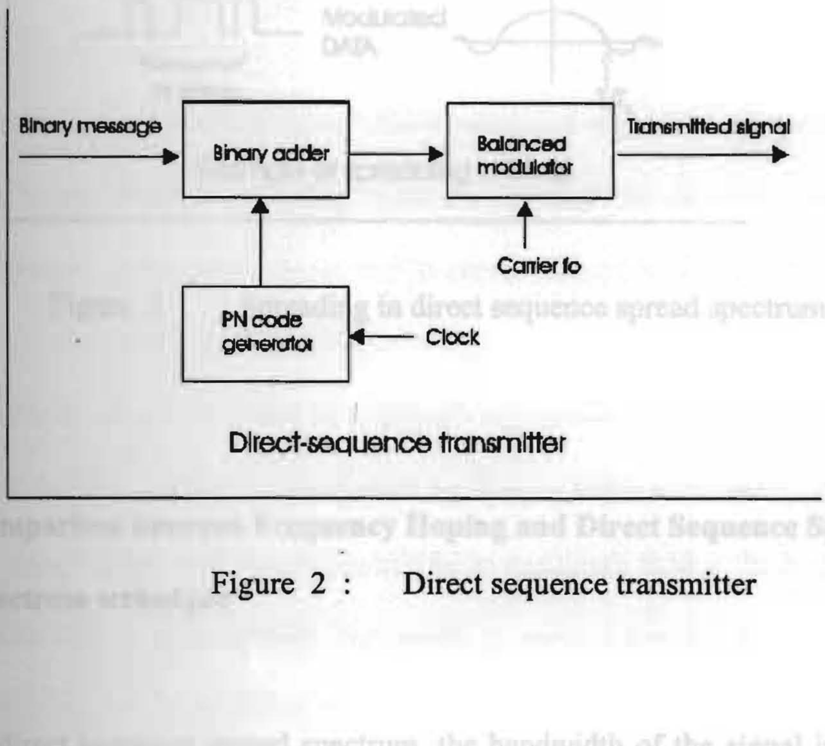

Figure 2 : Direct sequence transmitter

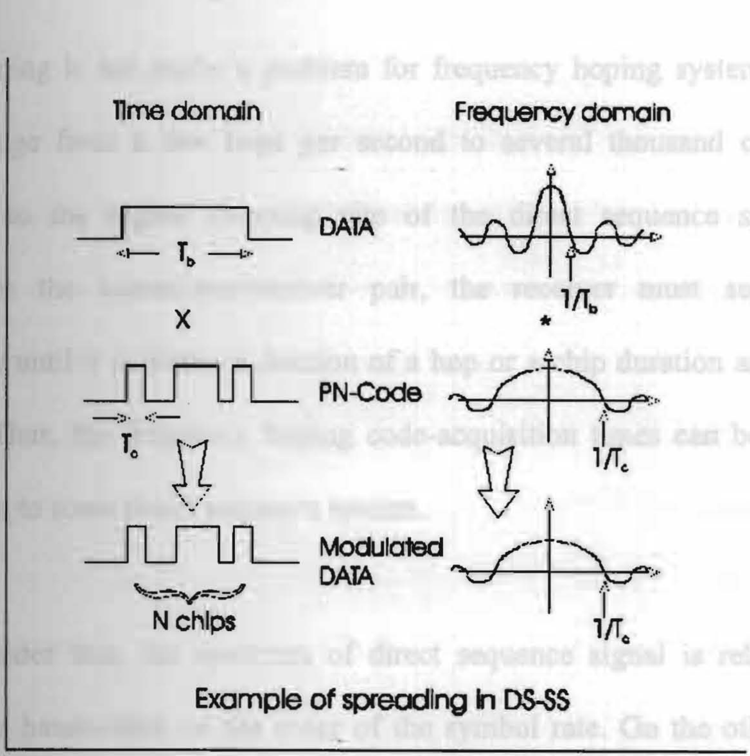

Figure 3 : Spreading in direct sequence spread spectrum

2.4.3 Comparison between Frequency Hoping and Direct Sequence Spread Spectrum technique

In direct sequence spread spectrum, the bandwidth of the signal is almost twice the clock rate of the PN code. High clock rate is needed for wide spreading bandwidth. This may cause some difficulties in synchronization as well as increasing equipment cost and power consumption. The bandwidth of frequency hoping system depends on the tuning range and can be hopped over a wide bandwidth easily.

Timing is not really a problem for frequency hoping system because hop rates usually range from a few hops per second to several thousand of hops per second, compared to the higher chipping rate of the direct sequence system. In order to synchronize the transmitter/receiver pair, the receiver must search its initial tie uncertainty until it is within a fraction of a hop or a chip duration and the signal can be detected. Thus, the frequency hoping code-acquisition times can be relatively short in comparison to some direct sequence system.

Besides that, the spectrum of direct sequence signal is relatively uniform for observation bandwidths on the order of the symbol rate. On the other hand, frequency hop is essentially a narrowband signal and its center frequency change frequently.

Both system can be useful in multipath mitigation. In direct sequence, multipath returns that are delayed by a chip period or longer relative to the desired return are essentially uncorrelated and do not contribute to multipath fading. In frequency hoping, one transmits over a wide enough bandwidth to ensure that the channel is frequency selective. While some frequencies are faded, others are not. As the signal hops around, some hops are lost while others get through. Thus, the signal require enough redundancy and interleaving to maintain an acceptable average error rate.

Frequency hoping is the most cost effective type to deploy for the transmission of data at 2Mbps or less. Direct sequence, having higher potential data rates, would be best for bandwidth intensive application.